Course Structure and Description

Machine Elements & Mechanisms I (ME&M-I)

14×2 hours Lectures on Mechanisms – L. Ciupitu

7×2 hours Laboratory – L. Ciupitu

PART I

- Introduction into the Theory of Planar Mechanisms: Statics, Kinematics, Kinetostatics and Dynamics; Mechanisms with Bars, Screws, Gears and Cams;
- Introduction to Mechanical Engineering Design: Threaded Fasteners & Power Screws and Springs

Course Outcomes

- Ability to apply knowledge of mathematics, mechanics, and technical drawing in the field of mechanical engineering
- Ability to identify a mechanism and its components
- Ability to study a mechanism from statics, kinematics, kineto-statics and dynamics points of view

Applications/Laboratory Outcomes

- Ability to design a mechanism to meet desired needs in the field of mechanical engineering
- Ability to study a mechanism from statics, kinematics, kineto-statics and dynamics points of view and to find the right results by using numerical methods and computers
- Ability to communicate effectively inside an heterogeneous group of students by working together and exchanging results

Prerequisites:

- Mechanics
- Mathematics
- Numerical methods
- Technical Drawing

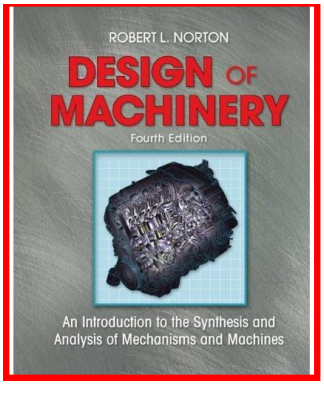
Evaluation

- Attendance (proven by notebooks): 10 points;
- Laboratory papers: 20 points;
- Homework: 20 points;
- Exam: 50 points.

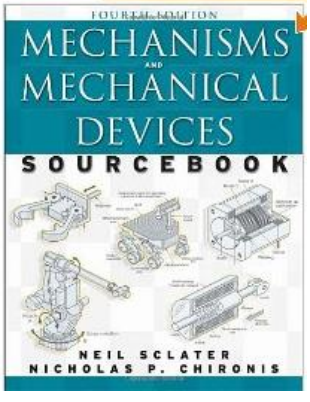
Passing Conditions

- Minimum of 50% from applications activity (25 points);
- Minimum of 50% from maximum points (50 points);

References



Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines – Robert L. NORTON, WCB/McGraw-Hill, 1992 (first edition), 1999 (second edition), 2003 (third edition), 2007 (fourth edition), 2011 (fifth edition)



Mechanisms and Mechanical Devices: Sourcebook - Neil SCLATER and Nicholas CHIRONIS, McGraw-Hill, 1991 (first edition), 1996 (second edition), 2001 (third edition), 2007 (fourth edition)

Chapter 1

- Definitions, introduction, history
- Structure of mechanisms
- Degrees of Freedom and Mobility

Brief history

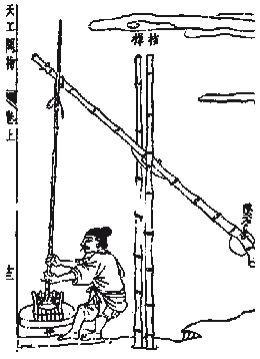
Ancient time:

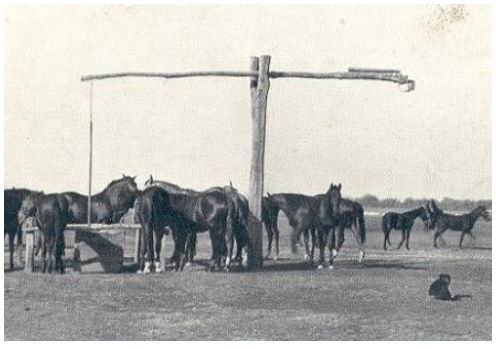
- Egyptians: lever, wedge (inclined plane), log roller – construction of pyramids;
- Mesopotamia: wheel and pulley (axle);
- Greeks: Archytas from Tarent (screw), Aristotel from Stagira (friction wheels and gears), Arhimede from Siracusa (water screw), Heron from Alexandria (syringe mechanism);
- Romans: military applications (catapults, wall scaling apparatus) and civil applications.

Modern time:

- Leonardo da Vinci, Galileo Galilei,
- Sir Isaac Newton, William Rowan Hamilton, James Watt,
- Joseph-Louis Lagrange, René Descartes
- Gottfried Wilhelm (von) Leibniz, Leonhard Euler,
- Franz Reuleux, Robert Willis,
- Gaspard Monge, Jean Nicolas Pierre Hachette,
- Pafnuty Chebyshev, Ivan Ivanovichi Artobolevsky
- Kurt Hain, Henry Brown
- Richard Hartenberg and Jacques Denavit

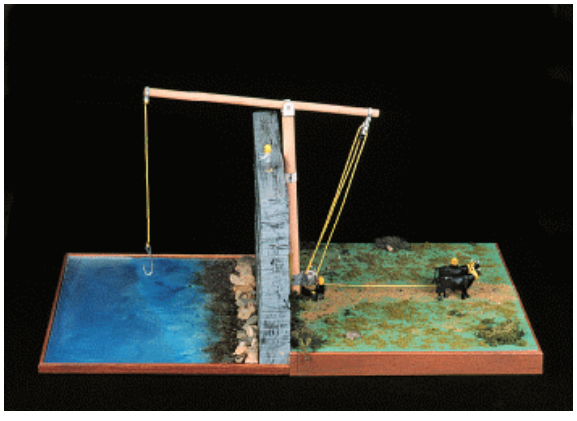
Simple and useful mechanisms





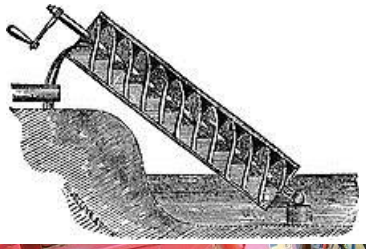
Sweep of a fountain with counterweight in order to help human for taking fresh water

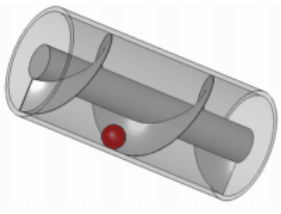
Archimedes claw mechanisms



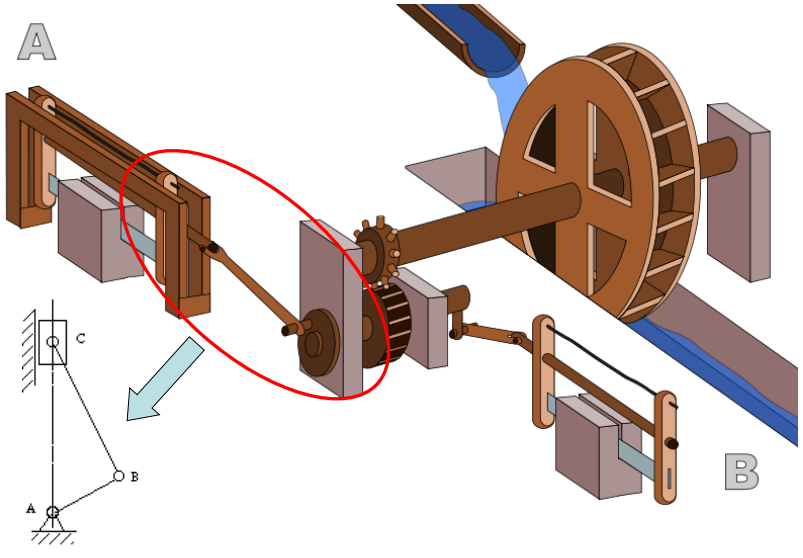
Sweep with an additional rotation around a vertical axis with transform the planar mechanism into spatial one

Archimedes screw mechanisms

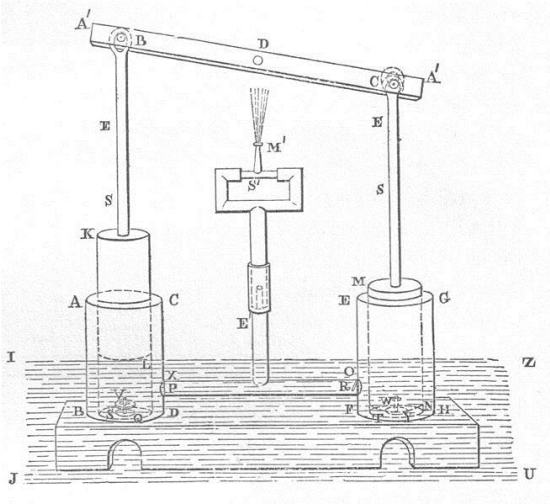


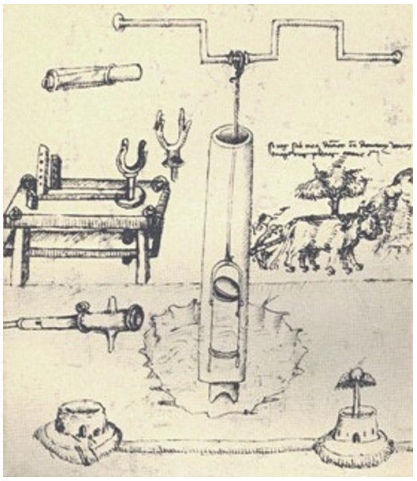


Roman mechanisms for cutting



Heron's pump

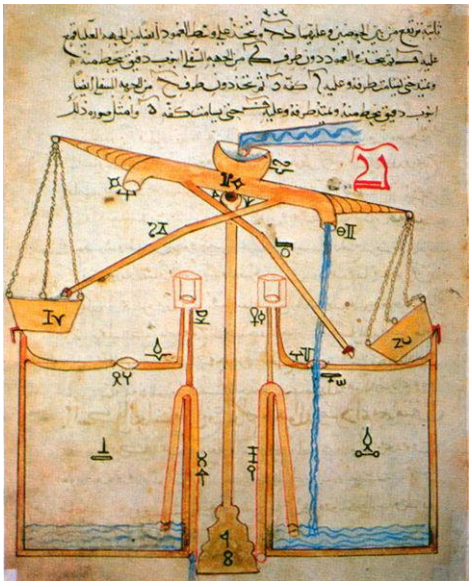




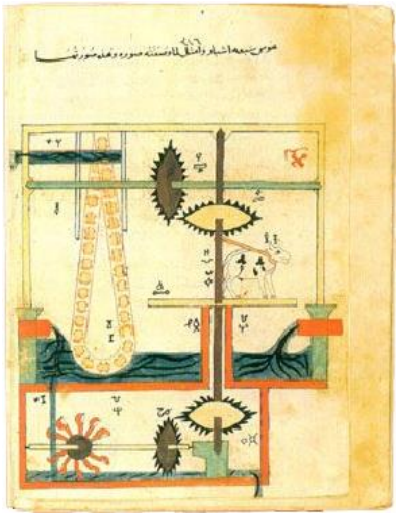
Pump mechanisms

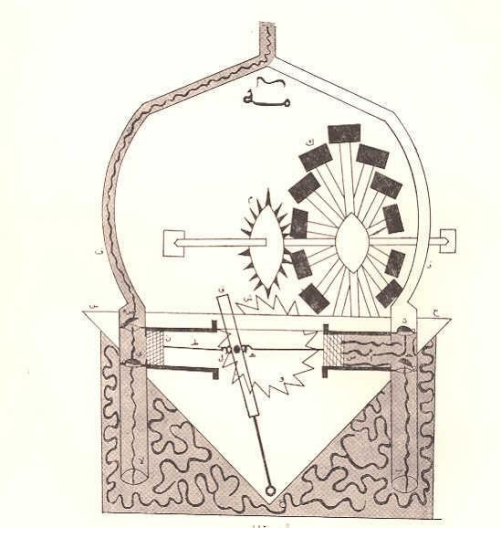
Reuleaux Educational Models

Middle Ages mechanisms



Al-jazari mechanisms (1)



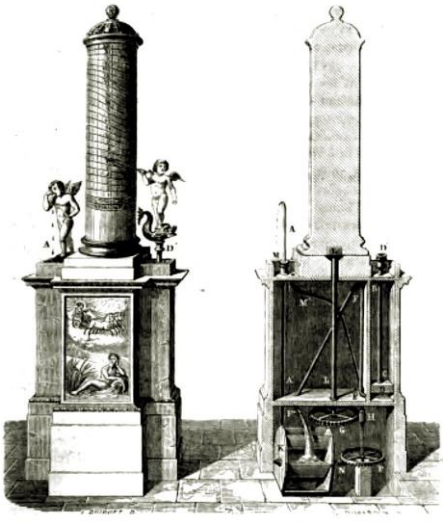


Clock mechanisms

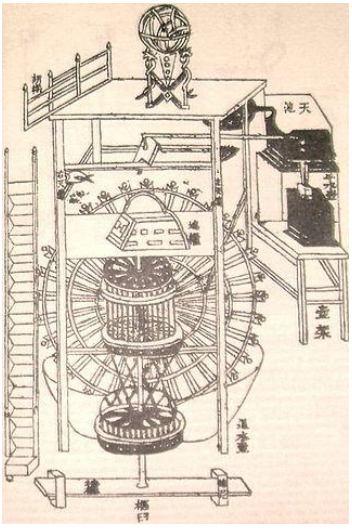
"Mobile" clock !

Replica build at Dubai - in *Battuta Mall*

Clocks actuated by water



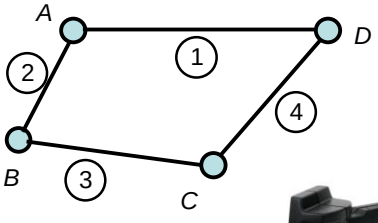
Ctesibius water clock (270 IC)



Su Song (1088) – cam mecanisms and chain transmission

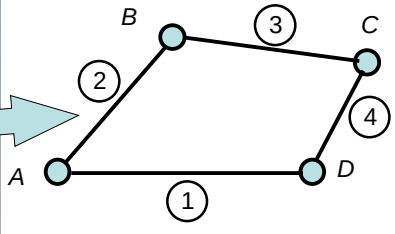
Mechanisms used in daily life

Locking pliers
(four-bars mechanism)



Machine

- transmits and transforms energy
- assemblage of mechanisms



Machine and Mechanism: general definitions

Machine

Assembly of machine elements linked together in order to transmit forces, motion and energy from a motor element to an effector element.

Mechanism

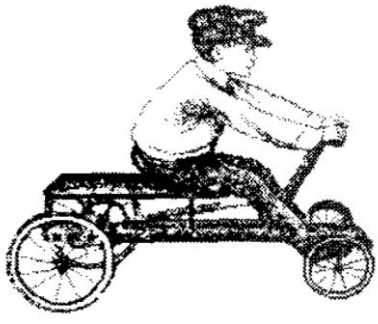
Part of a machine which transfer or transform forces and motions inside a machine.

A system of rigid bodies linked together in order to transfer or transform forces and motions from one point of a machine to another point.

Assembly of machine elements joined together in order to produce a specific motion inside a machine.

Machine versus Mechanism

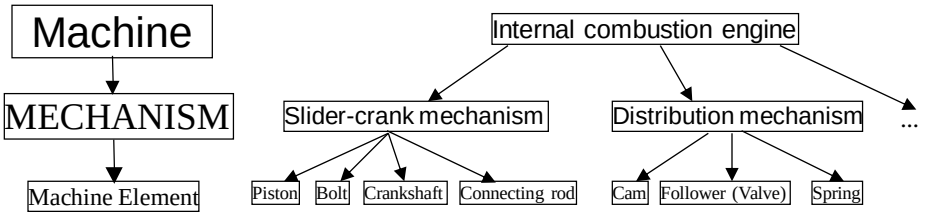
An assemblage of mechanisms that transmit forces, motion, or energy in a predetermined manner.

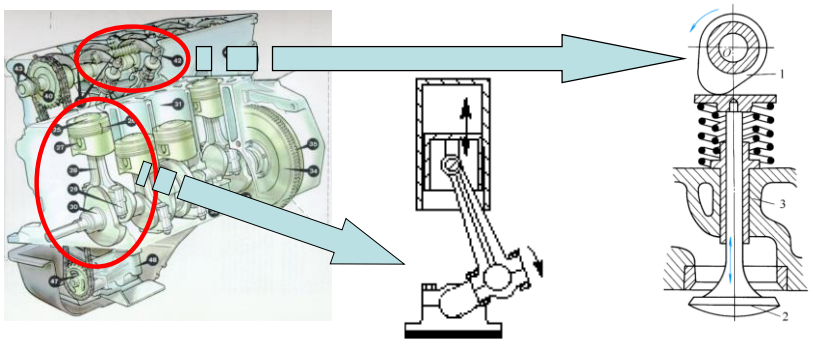


System of rigid bodies that provides the transformation of mechanical motion, and forces of a part into a definite motion and forces of another part.

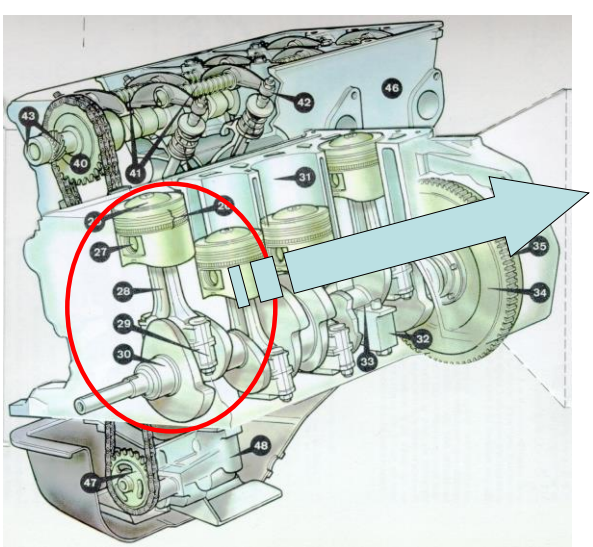
Part of a machine that provides the transmission and transformation of a definite mechanical motion.

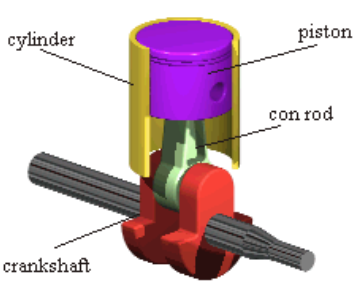
The structure of a machine

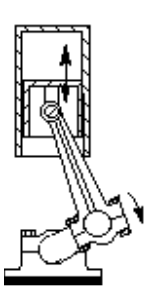


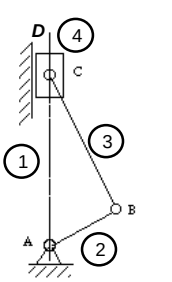


Mechanism study









skeleton outline

Slider-crank mechanism

Definitions

- **Theory of machines and mechanisms** = statics, kinematics and dynamics of multi-body systems
- **Statics:** study of forces and moments on multi-body systems at rest state
- **Kinematics**: study of motion on multi-body systems (position, velocity and acceleration of all points) without regard to forces
- **Kinetostatics**: study of equilibrium of forces on multi-body systems in motion by considering the inertial forces like real forces (D'Alambert principle)
- **Dynamics**: The study of movement of multi-body systems under the action of a system of forces

Definitions

Kinematics: The study of motion (position, velocity and acceleration) of multi-body systems without regard to forces

Forward problem: position, velocity and acceleration of a point of multi-body systems at a specific known values of independent variables

Inverse problem: independent variables required to give a specific position, velocity and acceleration to a point of multi-body systems

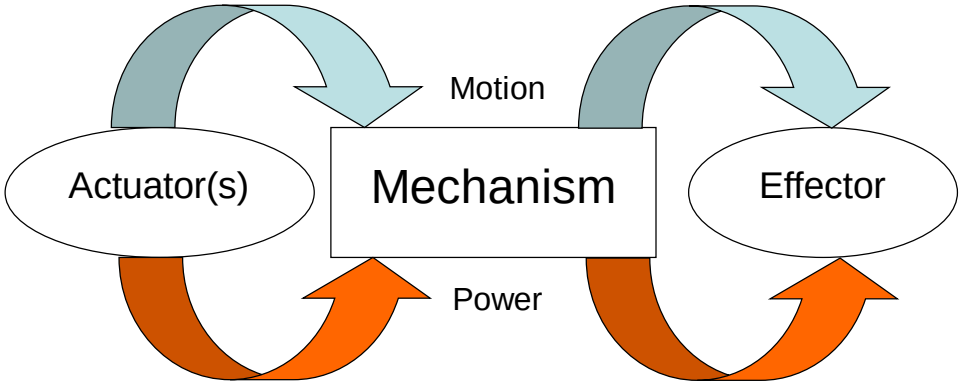
Dynamics: The study of movement of multi-body systems under the action of a system of forces

Forward problem (Kinetics): motion response of multi-body system under influence of given forces

Inverse problem: forces required to give specific response of multi-body system in terms of motion (i. e. Kinetostatics)

MECHANISM

Part of a machine which transmit motion and power from input point to output point



Structure of a mechanism

Mechanism = series of links (forming so called kinematic chains) joined together to produce a specific motion

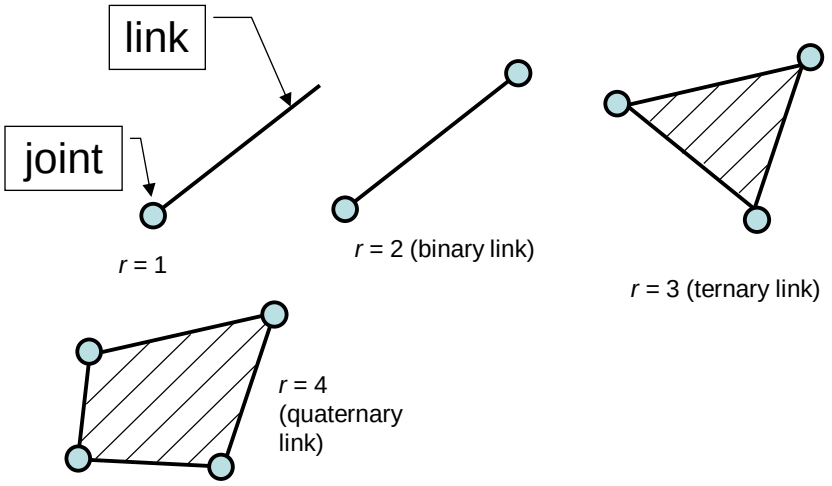
- Links (element, member)
  - links are considered rigid bodies, but bodies with small stiffness (like springs or cables) could be also involved;
  - one link could be formed by one single machine element or by assemblies of machine elements that are forming one rigid system which is transmitting same motion
- Kinematic pair (joint) = functions which express the joining between two links so that the relative motion between these two links is consistent
  - Revolute (turning, pin, hinged) joint
  - Sliding (prismatic, translational) joint
  - Spherical (globular), planar joint

General Hypothesis

1) Links are considered rigid bodies i. e. systems of particles where the relative position between particles does not change.

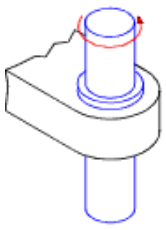
2) Pairing elements are functions which express the joining between two links so that the relative motion between these two is consistent. In first approximation there is no friction and no plays in joints.

Links

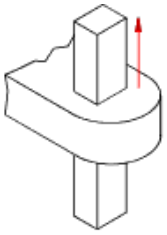


Order (or rank) of a link represents the number of link's joints

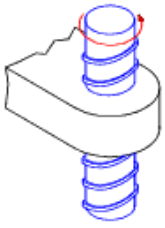
Joint types (1)



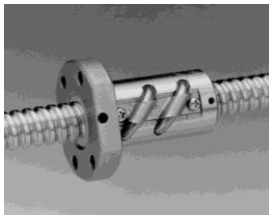
Revolute or Turning Pair...1-DOF



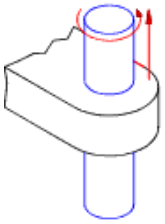
Prismatic (Sliding) Pair...1-DOF



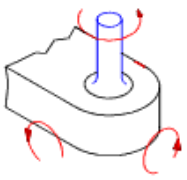
Screw Pair ...1-DOF



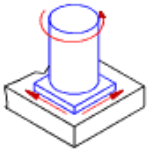
Joint types (2)



Cylinderical Pair ...2-DOF

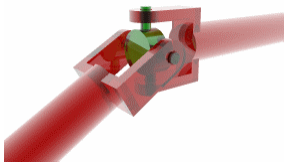


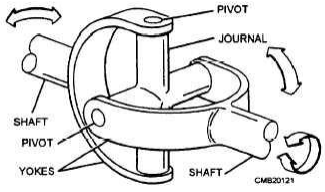
Spherical (Globular) Pair...3-DOF



Flat Pair ...3-DOF

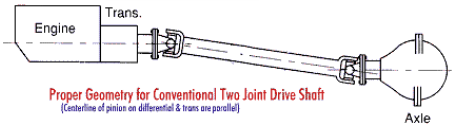
Universal joint (Cardan Joint, Hooke's Joint)





One joint (Hooke's Joint)

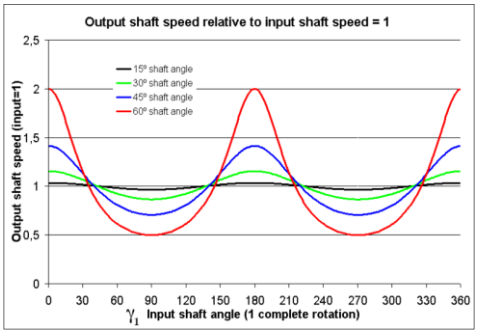
Linkage (with intermediary element - the "cross") of 3-rd family (spherical mechanism – all rotations have the axes concurent in the center of the "cross")

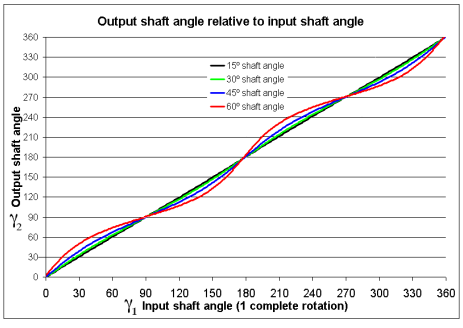


Two joints coupling (Cardan shaft, Spicer or Hardy Spicer joint)

https://en.wikipedia.org/wiki/Universal_joint

Universal joint kinematics





Classifications of pairs (1)

- From kinematics point of view kinematic pairs are classified in classes C_k, index k representing the number of restricted motions:
  - revolute, prismatic and helical pairs have $k = 5$;
  - cylindrical pairs have $k = 4$;
  - spherical and flat or plane pairs have $k = 3$.
- From geometrical point of view (contact between the links) kinematic pairs are classified in:
  - *lower pairs* (l_p) in case of surface contacts (Ex.: revolute, prismatic, helical, cylindrical, spherical and plane pairs);
  - *higher pairs* (h_p) in case of point or line contacts (Ex.: pairs found in cam and gear mechanisms which will be discussed in a special chapter).

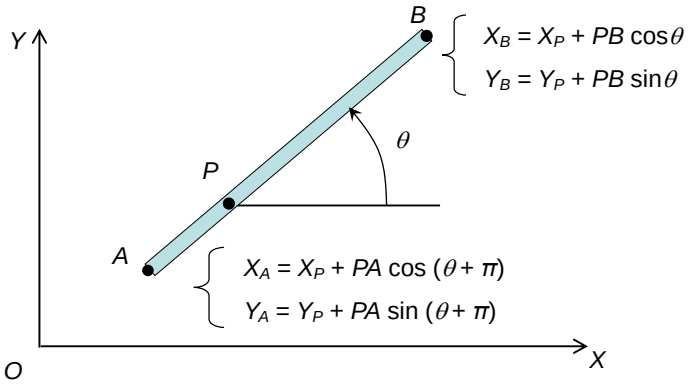
Classifications of pairs (2)

- From constructional point of view kinematic pairs are classified in:
  - *form-closed pairs* (Ex.: revolute pair, prismatic pair in two-side slot or slider in channel, cylindrical pair, helical pair, spherical pair);
  - *force-closed pairs* contact maintained by a force; usually the force of a spring (Ex.: prismatic pair in one-side slot, cam-follower higher pair, flat or plane pair);
- From functional point of view kinematic pairs are classified in:
  - *active pairs* (pair variables are the generalised co-ordinates of mechanism);
  - *passive pairs* (pair variables are function of active pairs variables).

Definitions

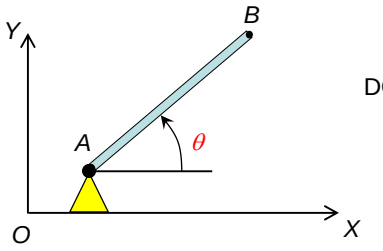
- Degrees of freedom (DOF): Number of independent parameters that define the position (configuration) of a multi-body system with respect to a coordinate axes system.
- Position of a rigid body is defined by:
  - 3 independent parameters in plane;
  - 6 independent parameters in space

Rigid body in plane

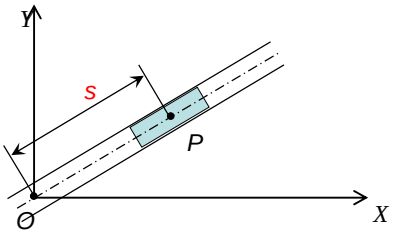


Independent parameters that define the position of a body in plane: X_P, Y_P and θ

Rocking/Sliding body in plane



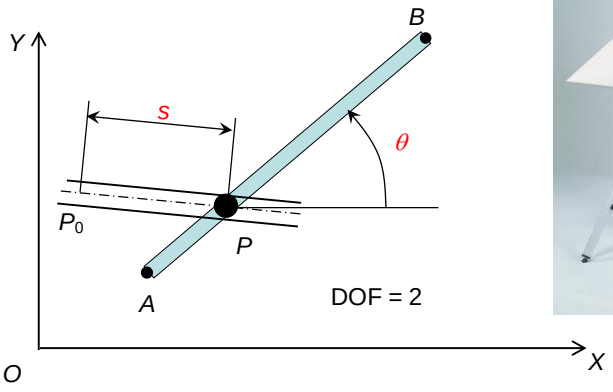
DOF = 1



Position of a *rocking body* is defined by one independent parameter: angle θ

Position of a *sliding body* is defined by one independent parameter: distance *s*

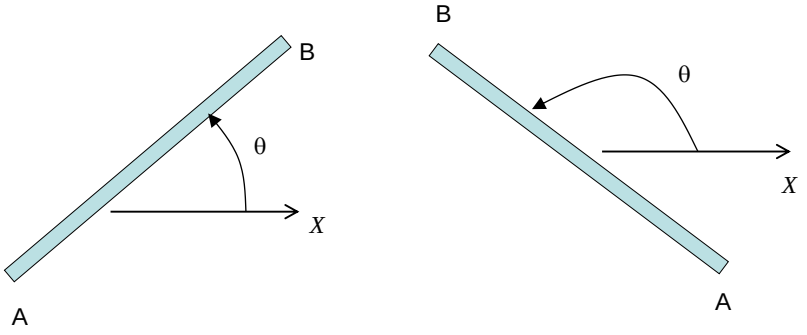
Rigid body with complex motion in plane



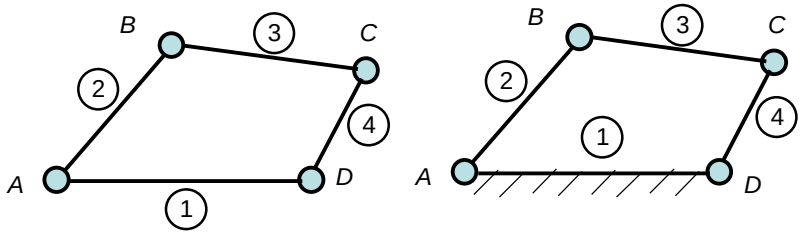
Position of the body is defined by two independent parameters: distance *s* and angle θ

Important observation

- Angles are measured counter clockwise from positive X axis, and are expressed in radians



Kinematic chains and mechanisms



- A kinematic chain represents a series of links joined together which are moving in a desmodromous way (i.e. movement of any link is according to the independent parameters)
- Mechanism is a desmodromic kinematic chain in which at least one link has been "grounded" or attached to the frame of reference (which itself may be in motion).

Dictionary

- Crank: link which makes a complete revolution and is pivoted to ground
- Rocker: link which has oscillatory rotation and is pivoted to ground
- Connecting rod (coupler link): link which has complex motion and is not pivoted to ground
- Ground: link fixed (non-moving) with respect to the reference frame
- Slider: element which is translating along a direction (which is usually a line)

Degrees of mobility or Mobility

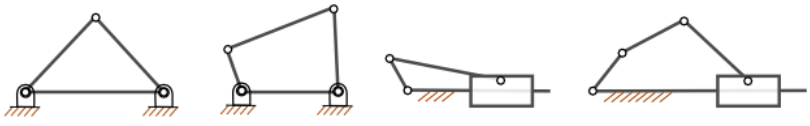
(sometime called also DOF in some books)

Cebishev-Grubler-Kutzbach formula of Mobility for planar mechanisms: $M_{planar} = M_3 = 3\,m - 2\,l_p - h_p$

where: m is the number of mobile elements

l_p is the number of lower pairs

h_p is the number of higher pairs



Truss

$m = 2,\ l_p = 3,\ h_p = 0$

$M_3 = 3x2 - 2x3 - 0 = 0$

Four-bar linkage

$m = 3,\ l_p = 4,\ h_p = 0$

$M_3 = 3x3 - 2x4 - 0 = 1$

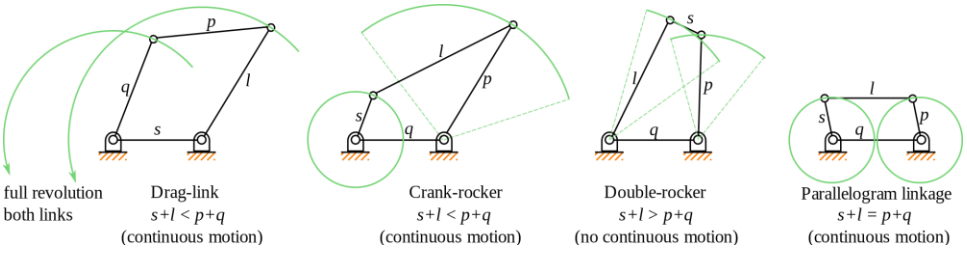
Crank-slider

Five-bar linkage

$m = 4,\ l_p = 5,\ h_p = 0$

$M_3 = 3x4 - 2x5 - 0 = 2$

Grashof condition on four-bar mechanism



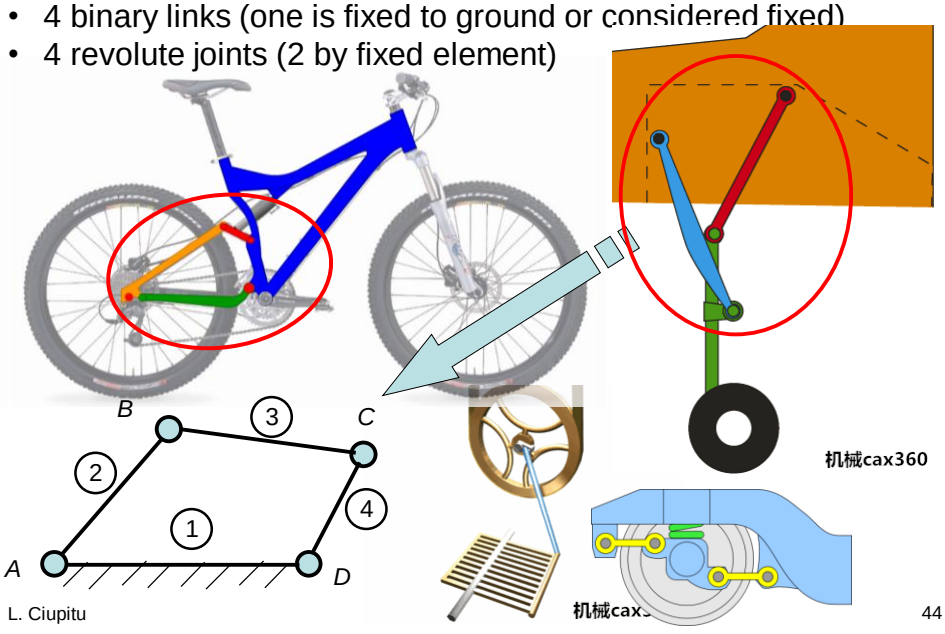
s is the shortest link,
l is the longest link,
p, *q* are the lengths of the other links

$M_3 = 3x3 - 2x4 - 0 = 1$

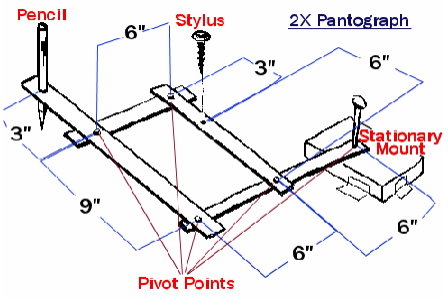
https://en.wikipedia.org/wiki/Four-bar_linkage

Four-bar mechanism

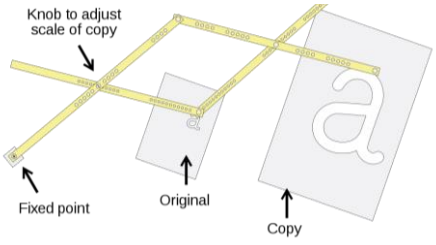
- 4 binary links (one is fixed to ground or considered fixed)
- 4 revolute joints (2 by fixed element)



Pantograph mechanism



$M_3 = 3x4 - 2x5 - 0 = 2$



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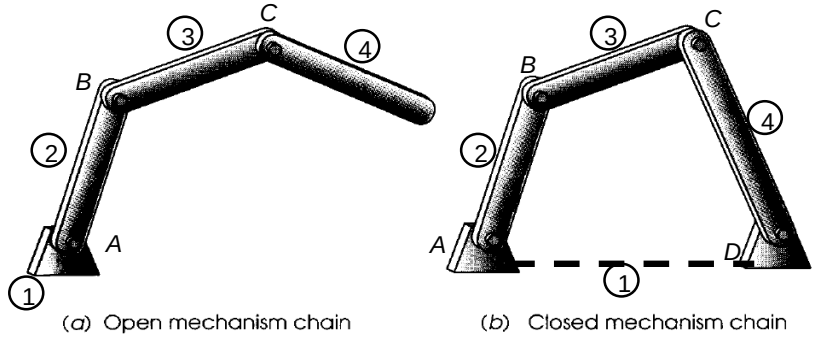
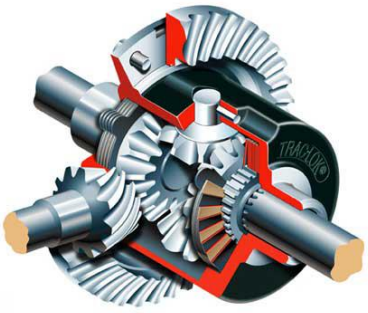
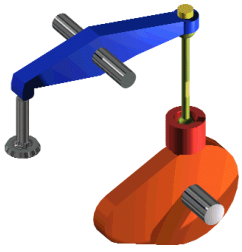


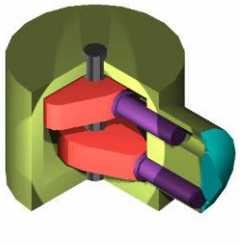
- Planar mechanism: Mechanism which moves in plane or in parallel planes
- Spatial mechanism: Mechanism moving in space

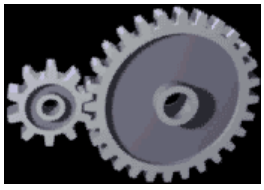
Classification of mechanisms

- Linkage mechanisms
- Screw mechanisms
- Cam mechanisms
- Gear mechanisms

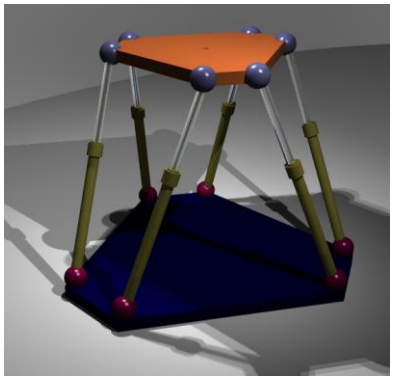


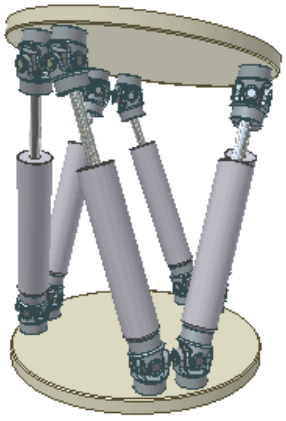






Gogh-Stewart Platform (spatial parallel mechanisms)

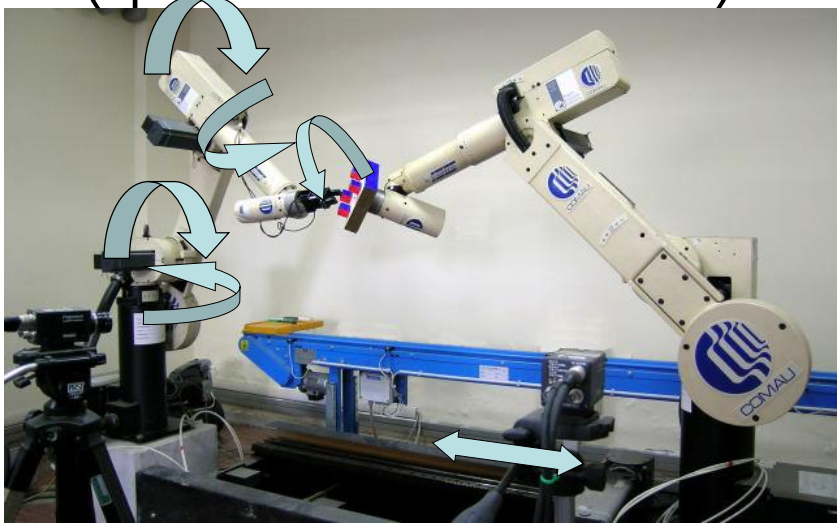




$$M_{space} = M_6 = 6\,m - 5\,C_5 - 4\,C_4 - 3\,C_3 - 2\,C_2 - C_1$$

$$M_6 = 6x13 - 5x6 - 4x0 - 3x12 - 2x0 - 1x0 = 12\ !$$

Industrial Robots
(spatial serial mechanisms)



$M_{6\ left\ robot} = 6x5 - 5x5 = 5$ $M_{6\ right\ robot} = 6x6 - 5x6 = 6$

Conclusions

- Theory of machines and mechanisms
- Mechanisms analysis:
  - Structure of mechanisms
  - Kinematics of mechanisms
  - Kinetostatics of mechanisms
  - Dynamics of mechanisms
- Mechanisms synthesis